ENVIRONMENTAL REMOTE SENSING FOR MONITORING PLANT HEALTH

TECHNOLOGY DESCRIPTION

This project involves testing several different types of remote sensors in parallel on populations of plants subjected to stress in a controlled environment. The testing identifies the best sensor, or group of sensors, for acquiring optical signatures from vegetation as an indicator of contamination in the soil or groundwater. Classical and more novel methods for analyzing the data acquired from all of the sensors are being pursued to make best use of the raw data obtained. These methods include neural net analysis and higher-order derivative analysis techniques. To understand the entire plant stress picture more completely, these same plant populations are also analyzed biochemically, anatomically, and morphologically. In addition to passive reflectance as a baseline, laser-based technology is being developed as a more chemically sensitive optical probe; a new state-of-the-art passive hyperspectral imager is also producing promising results. For the laser-induced fluorescence (LIF) techniques, a pulsed ultraviolet laser (normally eye-safe) is used to excite fluorescence in the vegetation being surveyed. The fluorescence is collected spectrally in the 400- to 800-nm region. Fluorescence data can be collected in full daylight. Sensor standoff can be anywhere from a few feet to hundreds of feet; the sensor system could even be used on a low-altitude airborne platform (it has already been aircraft mounted more than once). The data collected are analyzed for indications of stress in the plants that may signify an environmental problem (change detection) such as subsurface contamination.

No comparable baseline technology currently exists for surveying large areas for minor to moderately severe subsurface contamination. Passive remote sensing technologies currently in use can see only very severe problems, usually involving dead or dying vegetation. Unless the contamination is extremely heavy, surveys for subsurface contamination most often rely on spot checks using groundwater or soil sampling techniques that generally require laboratory analysis; this makes large-area ground surveys very labor intensive and, therefore, difficult and expensive. A faster, cheaper technique is needed.

TECHNOLOGY NEED

There is a current and future need to monitor U.S. Department of Energy (DOE) sites:

- To detect changes in vegetation health during very long term monitoring of contaminated sites and in carrying out monitoring as part of stewardship of land responsibilities. (The latter is a very large problem for DOE that is just beginning to receive more attention.)
- To pinpoint existing contamination in soil and groundwater for later cleanup.
- To periodically monitor contained sites for possible leakage.
- To demonstrate cleanliness of remediated sites.

Because of the large areas of land involved, some of which are not easily accessible, monitoring based on remote sensing will, in most cases, be the safest and most cost-effective monitoring method. Coupling remote sensing data with ground-truth data has been shown to be a cost-effective way to eliminate the need for detailed point sampling of large areas of land. Remote sensing, however, has been limited by the lack of data available for using vegetation cover as an indicator of subsurface and surface contamination. This work is focused on determining the phenomenological origins of the changes in vegetation exposed to contaminants in order to understand the causes of the observed changes as well as to establish the best remote sensing methods to measure them. LIF was chosen to complement existing passive techniques because LIF can detect altered fluorescence in plants resulting from stresses such as metal contamination. Collaboration with other investigators has allowed evaluation of state-of-the-art passive hyperspectral imagers alongside laser-based techniques. The approach of the work is to identify, compare, and develop the most effective vegetation remote sensing technologies for the detection of subsurface contamination at DOE sites. This approach is emphasizing, but is not limited to investigations using LIF techniques. In parallel, stressed plants are also measured anatomically, biochemically, and physiologically for a better understanding of the complete problem.

A few specific examples of Site Technology Coordination Group (STCG) needs are:

- SR99-3025 - Monitoring Technologies
- ORBW-08 - Long-Term Performance Assessments
- AL-09-01-03-SC – Long-Term Monitoring Techniques
- AL-09-01-30-SC-S - Vadose Zone Monitoring Systems
- AL-07-09-03-SC - Long-Term Surveillance and Maintenance Program at Several Facilities (e.g., to evaluate the consequences of bio-intrusion at Uranium Mill Tailings Remedial Action (UMTRA) sites.)
- AL-07-06-01-SC - Locate Chromium (Cr) Contamination at the Pantex Plant: "In-field characterization technology to quickly identify and delineate contaminated areas"
- AL-07-01-01-SC - Identify Helium (He) and Barium (Ba) "Hot Spots" for Cleanup at Los Alamos National Laboratory
- NV-18-9801-05 - Nevada Test Site: Efficient Monitoring Systems to Monitor Plant Root Penetration and Contaminant Uptake
- SR-3025 - Savannah River Site: Monitoring Integrity of Contained Waste Sites

Work has recently begun at the Savannah River Site (SRS) where there is considerable interest in pursuing remote sensing techniques; portions of their existing passive multispectral flyover data are being examined. This site is planned to be the first site for conducting field measurements of stressed versus unstressed plants growing *in situ* at a DOE site. This is where the technology would first be demonstrated.

TECHNOLOGY BENEFITS

The LIF technology being developed will allow faster, cheaper, and less labor-intensive surveys of large areas (by ground or air) and will provide more complete ground coverage. The new remote sensing methodology will make it feasible to monitor contaminated sites regularly at a reasonable cost. It will also make it possible in many cases to detect contamination problems earlier than with currently used remote sensing techniques; i.e., before the problems manifest as visible dead or dying vegetation, thus minimizing the likelihood of a negative public reaction. Remote sensing allows better access for certain difficult-to-reach areas (e.g., swampy areas), and reduces or eliminates the time that must be spent by workers in dangerous and/or contaminated zones. This technology also eliminates the need to handle soil or water samples (perhaps contaminated with other things than the expected contaminants) unless indicated for ground truth verification. In fact, unlike water and soil sampling techniques, the remote sensing techniques produce no waste; they are 100-percent nonintrusive. In summary, the technology being developed will be faster, cheaper, and safer than point sampling techniques. It will allow surveys of areas that are not easily accessible and provide more complete coverage data than point sampling. The technology being developed will also become the baseline technology for environmental surveys where no comparable baseline technology presently exists, and it will be especially valuable and applicable in long-term site monitoring requirements.

TECHNOLOGY CAPABILITIES/LIMITATIONS

The primary limitations of the techniques being developed are (1) the lack of actively induced laser-, or otherwise-induced, fluorescence plant health and stress data needed to identify contaminant stress in plants, and (2) the lack of field experience and data with both laser-induced and passive-hyperspectral techniques. It is not currently known what the techniques can and cannot be expected to do in the field because tests to date have been limited primarily to the laboratory, and at this time not all comparison data (active vs. passive systems) have been analyzed, nor have the new data analysis techniques been fully refined. This technology should be effective in soils to depths limited only by penetration depth of roots. It is not currently known how specific the technique can be made, but it should not be expected to be capable of differentiating between specific contaminants; rather, its primary value will be in (pre-visual) change detection. This will depend partly on the results of current investigations of several data-analysis methodologies, as well as the outcome of new research indicating that it may be possible to code plants to be responsive to specific contaminants.

Laser-induced fluorescence (LIF) spectra and fluorescence images of several species of healthy and stressed plants are studied for their value as surface and subsurface contaminant indicators.

COLLABORATION/TECHNOLOGY TRANSFER

Current collaborations are as follows:

- Walt Disney World/Epcot Center: Collaboration/in-kind support including greenhouse space, office space, temperature-controlled laboratories and chambers, laboratory equipment, consumables budget, and 5 to 10 percent time-use of a plant nutritionist, entomologist, pathologist, technician, horticulturist, engineer, and secretary.
- National Aeronautics and Space Administration (NASA)/Kennedy Space Center and Dynamac Corp.: Collaboration and in-kind support including laboratory space and use of equipment (high-pressure liquid chromatograph, spectroradiometer, pyranometer, microscopes, histology microtome, and staining system, balances, etc.), consumables budget, and some personnel support (leaf histology and biochemistry).
- NASA/Stennis, Louisiana: Hyperspectral imaging equipment brought to group data-takes for measurements, with subsequent sharing of information.
- Georgia State University: Visible and near-infrared (NIR) imaging system brought to group data-takes at Epcot with subsequent sharing of information.
- Kansas State University: Plant physiology and leaf biochemistry.

- Florida Institute of Technology: Advanced data analysis.
- Citrus Research Education Center (University of Florida): Plant viruses and tagging plants with green fluorescent protein (gfp).
- Rutgers University: Heavy metals, gfp.
- Army Corps of Engineers, Topographic Engineering Center, Virginia: Hyperspectral and fluorescence data fusion studies.

An on-site demonstration has been planned at SRS, perhaps beginning as soon as this fiscal year. Interest about commercial applications has been expressed only through inquiries; there has been no concrete action so far. Interested commercial entities include:

- Walt Disney World Company: Measuring stress in transplanted mature trees.
- Weyerhaeuser Corporation: Monitoring of timber-producing forests.
- Schwartz Electro-Optics: Sensors for agricultural spraying.

ACCOMPLISHMENTS AND ONGOING WORK

A Memorandum of Understanding (MOU) was initially signed between DOE and Disney and is still in effect. Following this, a plant measurement laboratory was established at The Land, Epcot, with a full-time, on-site plant scientist (contracted by the Special Technologies Laboratory (STL) through Dynamac Corp.) and technical support. The laboratory has been outfitted with much state-of-the-art instrumentation, plus custom instrumentation built by STL, including a multi-axis robot on a 5-meter track, installed in the greenhouse and integrated with a suite of three sensors for automated data collection. A laser-induced fluorescence imaging (LIFI) system was modified for plant measurements and a laser-induced fluorescence spectroscopy (LIFS) system was built and added to it; this portable system is used at Epcot and other field locations. With the customized and evolving instrumentation, the on-site plant expertise, and the ever-growing number of collaborators from government and academia, the facility at Epcot is becoming a world-class plant measurement facility, specifically in support of finding remote sensing solutions for certain DOE problems.

Recently, the project has been growing various plant species (specifically those relevant to DOE sites) under controlled conditions and stressing them with various levels of several different metals. While fluorescence is emphasized, these plants are measured with various sensors, both active and passive, and the results are compared to evaluate sensor performance for stress measurement. Baseline natural variation (plant age, season, time of day) data have also been collected, as have data regarding biochemical, anatomical, and structural changes, in an attempt to correlate what is happening in the stressed plant with changes in the sensed optical signatures.

Specific accomplishments for the past year (end of FY 1998 through the first half of FY 1999) include the following:

- Conducted group data-takes in March, June, July, and December 1998 wherein sets of control and stressed plants are measured at the same time with a wide array of instrumentation including LIFI, LIFS, excitation-emission spectra (EES), classical reflectance, hyperspectral imaging (state-of-the-art instrumentation. Analysis (biochemistry, anatomy, and morphology) of plant tissue is provided cost-free by collaborators; the results are then compared and correlated.
- Conducted data collection has been focused on species growing at the SRS and Oak Ridge National Laboratory; i.e., Bahia grass, loblolly, slash pine, and sweetgum. Zinc and copper are currently being used as stressors.
- Began work with a DOE site (SRS) interested in the technology; an experimental plan for on-site work is being formulated with them.
- Continued work with collaborators, the primary being government (NASA/Kennedy Space Center and NASA/Stennis), academia (University of Georgia), and private industry (Walt Disney World Company and Dynamac Corp).

- Tested more sophisticated spectral data analysis techniques; neural net analysis appears the most promising and is being pursued with new EES data sets.
- Built and demonstrated a smaller, lighter, more rugged, and more user-friendly LIFS system; the LIFI system was also miniaturized and ruggedized on another job.
- Built a laser energy and a wavelength calibration channel into the LIFS system.
- Continued collection of baseline (unstressed) plant data (14 plant species), some of it using the robot system in the Epcot greenhouse to measure natural variations in plant signatures.
- Conducted a low-key effort to look into gfp technology (used LIFI and LIFS to examine some plants with a gfp-tagged virus).
- Conducted experiments on the effects of light on fluorescence remote sensing signatures including light-adapted vs. dark-adapted plants, plants grown under different light levels, and plants measured under different light levels (including rapidly changing light levels).
- Measured fluorescence signatures as a function of laser power.

The results (analyzed data) collected from the laboratory experiments are coming together, and it should be possible to reach some important conclusions and recommendations in the next year (as work shifts to the field). Several important preliminary results can already be stated:

- Both LIFI techniques and passive hyperspectral imaging technologies work efficiently in detecting metal stress in all plant species studied.
- LIFI techniques have been able to detect some pre-visual stress signatures.
- Preliminary results indicate that LIF data, unlike that from any passive system, can be collected and appear valid over a wide range of light conditions–from full sun to darkness.

TECHNICAL TASK PLAN (TTP) INFORMATION

TTP No./Title: NVO-5-C2-21 - Environmental Remote Sensing for Monitoring Plant Health

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